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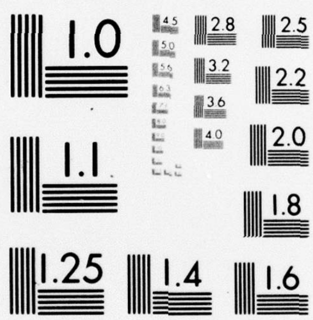

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ALLOWING FOR THE WATER PERMEABILITY OF FROZEN GROUND SCREENS DURING THEIR FORMATION

A.I. Pekhovich

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

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FROZEN GROUND DAMS

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Creation of water-impermeable cofferdams in an important and sometimes extremely complex problem which builders, in particular those who construct hydraulic facilities, are frequently called upon to solve. One of the most widely used methods of constructing water-impermeable dams is the method of artificially freezing ground which, as is known, consists of the following: Freezing columns are implanted in the dam with a certain distance between them. Brine is circulated in the columns, and is cooled by a refrigeration

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device. Initially individual frozen ground cylinders are formed around each column, and these cylinders then join into a single water-impermeable mass. It is obvious that between the beginning of freezing and the complete interconnection of the frozen ground cylinders, the rate of the filtration flow through the cofferdam changes. The question of how large the filtration flow is during this period is not only of theoretical, but also of considerable practical interest, for instance in determining the value of the heat flow from the nonfrozen ground to the frozen ground cylinders (in calculating the freezing speed), in determining the possible value of the filtration flow rate through the cofferdam when the frozen ground cylinders do not join completely (the problems of drainage from the excavation), etc. Unfortunately, as far as we know, no appropriate calculation method has yet been devised. This article is designed to fill this gap.

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1. Introduction. Creation of water-impermeable cofferdams is an important and sometimes extremely complex problem which builders, in particular those who construct hydraulic facilities, are frequently called upon to solve. One of the most widely used methods of constructing water-impermeable dams is the method of artificially freezing ground which, as is known, consists of the following.

Freezing columns are implanted in the dam with a certain distance between them. Brine is circulated in the columns, and is cooled by a refrigeration device. Initially individual frozen ground cylinders are formed around each column, and these cylinders then join into a single water-impermeable mass.

It is obvious that between the beginning of freezing and the complete interconnection of the frozen ground cylinders, the rate of the filtration flow through the cofferdam changes. The question of how large the filtration flow is during this period is not only of theoretical, but also of considerable practical interest, for instance in determining the value of the heat flow from the nonfrozen ground to the frozen ground cylinders (in calculating the freezing speed), in determining the possible value of the filtration flow rate through the cofferdam when the frozen ground cylinders do not join completely (the problems of drainage from the excavation), etc. Unfortunately, as far as we know, no appropriate calculation method has yet been devised. This article is designed to fill this gap. However, we should note here that the problem which will now be examined is similar to the one posed previously in 1950 by Ye. A. Chugayeva [1] and in 1952 by V. P. Nedriga and Ye. Ya. Khapalova [2]; the difference between this problem and theirs consists only of the fact that instead of a series of frozen ground cylinders they had only a series of rectangular sheet piles with slits.

It is necessary to keep in mind the fact that, as investigations carried out by the Institute of Hydraulic Engineering have shown, frozen ground cylinders created under filtration flow conditions have an almost circular transverse cross-section although the cylinder axes are shifted in the direction of the flow [3, 4].

2. Statement of the Problem. The problem can be formulated as follows.

A cofferdam is given with a rectangular transverse cross-section and width H (Figure 1). Frozen ground cylinders with radius R are arranged on the cofferdam in a single row with a uniform distance of S between them. The cofferdam stands on a water-impermeable base. The water is filtered under the action of the constant head difference between the lateral boundaries of the dam. No filtration around the cofferdam is permitted. The filtration factor of the ground which comprises the cofferdam is the same at every point and does not vary over time. The speed with which the frozen ground cylinders increase is very low (no more than 3-6 cm/day), which makes it possible to

assume that the motion of the filtration flow has been established. The speed of the water at every point is found to be within limits at which the linear filtration law of Darsy applies. It is necessary to calculate the change in filtration flow rate during the freezing period before the first ground cylinders join, i.e., define the dependency

$$\nu = \frac{Q}{Q_0}, \tag{1}$$

where Q_0 is the rate of the filtration flow before the freezing begins;

Q is the rate of the filtration flow in the presence of frozen ground cylinders.

The factor ν changes from unity to zero and characterizes the relative anti-filtration effect of the frozen ground cylinders.

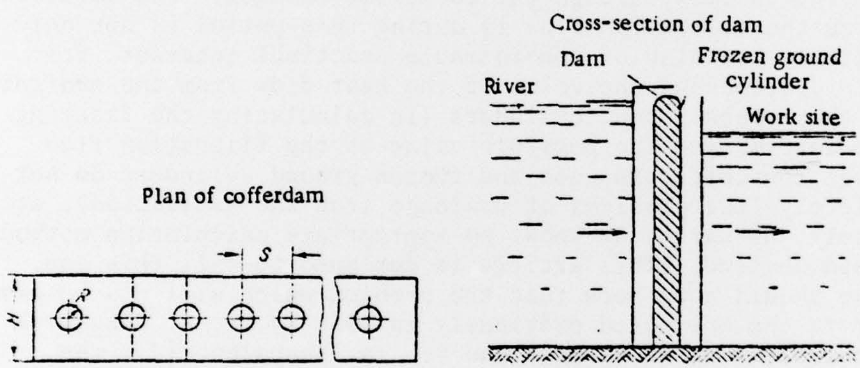

Figure 1. Diagram of Cofferdam.

3. Approximate Problem Solution. We will examine the problem as [Translator's Note: one word obscured]. In order to solve it we will use the well-known "fragment" method proposed by Academician N. N. Pavlovskiy [5].

The essence of this method consists of breaking the filtration area down into sections in such a way that the dividing lines between the sections can be approximately adopted as the equal head line. Then we determine the filtration resistance between these lines for each section individually; by then summarizing the resistances of all the sections, we find the total filtration resistances of the area in question.[1]

It is obvious that the unknown change in filtration flow is equal to:

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[1]The concept "filtration resistance" is identical to the more widely known concept "electrical resistance" and "thermal resistance".

$$\nu = \frac{\chi}{\chi + F_a}, \tag{2}$$

χ is the filtration resistance of the cofferdam before freezing begins (basic filtration resistance);

F_a is the additional filtration resistance created by the frozen ground cylinders.

Expression (2) remains unchanged if instead of the entire cofferdam we examine a portion of the dam with a length equal to the distance between the axes of the frozen ground cylinders.

In this case we have

$$\chi = \frac{H}{S}, \tag{3}$$

where, as before, H is the thickness of the cofferdam;

S is the distance between the axes of the frozen ground cylinders.

The additional filtration resistance is equal to (see Figure 2)

$$F_a = \int_{-R}^{+R} \frac{dx}{2y} - \varepsilon = \int_{0}^{R} \frac{dx}{y} - \varepsilon, \tag{4}$$

where

$$\varepsilon = \frac{2R}{S}. \tag{5}$$

We should note that

$$x = \sqrt{R^2 - \left(\frac{S}{2} - y\right)^2}. \tag{6}$$

By substituting (6) into (4), we find

$$F_a = \int_{\frac{S}{2}-R}^{\frac{S}{2}} \frac{\frac{S}{2} - y}{y\sqrt{R^2 - \left(\frac{S}{2} - y\right)^2}} dy - \varepsilon = \frac{1}{\sqrt{1-\varepsilon^2}}\left(\arcsin \varepsilon + \frac{\pi}{2}\right) - \frac{\pi}{2} - \varepsilon. \tag{7}$$

By substituting (3) and (7) into (2), we find the following, fairly simple computation equation which is the solution to the stated problem:

$$\nu = \frac{\chi}{\chi + \frac{1}{\sqrt{1-\varepsilon^2}}\left(\arcsin \varepsilon + \frac{\pi}{2}\right) - \varepsilon - \frac{\pi}{2}}. \tag{8}$$

where

$$\chi = \frac{H}{S}. \tag{9}$$

By utilizing equation (8), we can plot a graph which makes it possible to directly determine the values $\nu = f(\varepsilon, \chi)$. This graph (Figure 3) clearly shows that as the dimensions of the frozen ground cylinders increase, the filtration rate decreases.

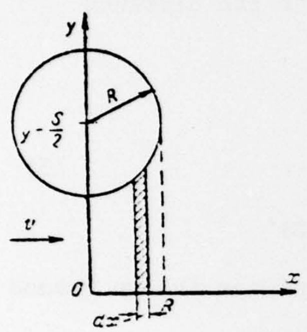

Figure 2.

Computation equation (8) is approximate. Therefore, in order to check its precision it was compared with the data of electro-hydrodynamic analogy tests carried out by G. S. Shadrinyy in the All-Union Scientific Research [Translator's Note: last letter obscured]; for this purpose graphic representations of [one word obscured] of a filtration flow carried out by us were utilized. It turned out that the precision of the data obtained by means of computation equation (8) was less than the precision of the check methods themselves (approximately ±5%).

The above-cited material, in particular expression (7), makes it quite easy to obtain a computation equation which analytically determines the change in filtration flow rate in a more general case, specifically in the case where there are n rows of cylinders.

In this case

$$\nu = \frac{H}{H + \sum_{i=1}^{i=n} S_i \left(\frac{\arcsin \varepsilon_i + \frac{\pi}{2}}{\sqrt{1 - \varepsilon_i^2}} - \frac{\pi}{2} - \varepsilon_i \right)}, \tag{10}$$

where index i indicates the number of the row.

When the distances between the cylinder axes are equal in all rows, equation (10) is converted into equation (8); however, in this case in contrast to (9)

$$\chi = \frac{H}{n \cdot S}. \tag{11}$$

An examination of additional filtration resistance is of particular interest.

In his work [6] S. N. Numerov concludes that "from the viewpoint of the filtration flow rate, a vertical water-impermeable barrier is equivalent

to elongating the path of uniform filtration". In the case examined by us the frozen ground cylinders creates an additional anti-filtration effect which is equivalent to a cofferdam of thickness $H_a = F_a \cdot S$.

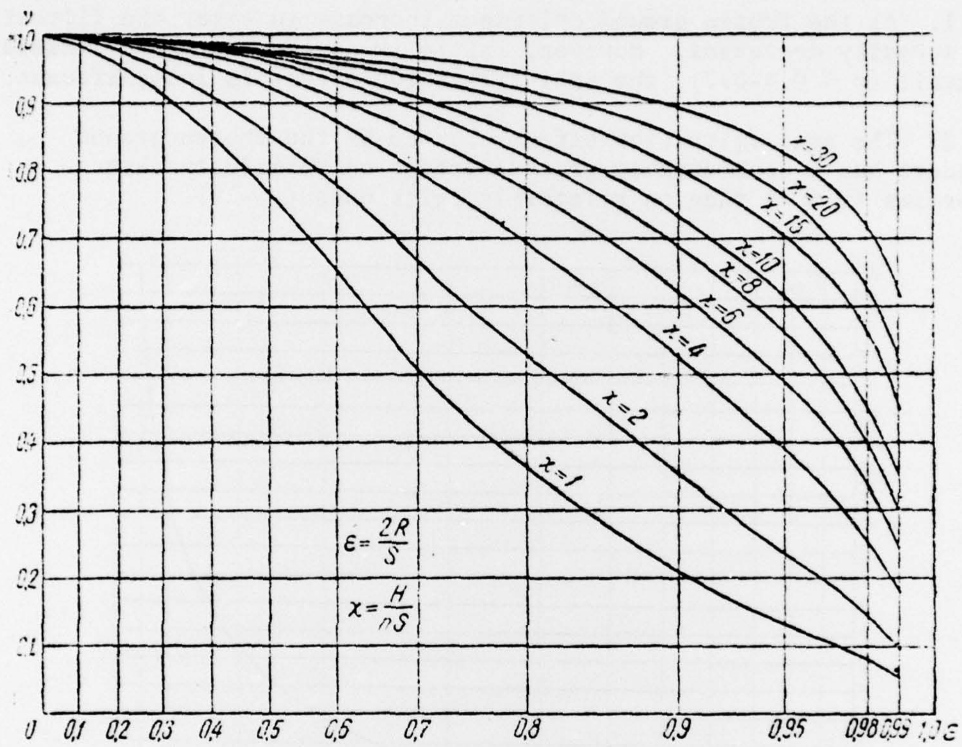

Figure 3. Relative Change in Filtration Flow Rate Through a Cofferdam When the Frozen Ground Cylinders Increase.

It is obvious that the value of the additional filtration resistance is not a function of the thickness of the cofferdam.

However, it is necessary to emphasize that the relative, as well as the absolute change in the filtration flow rate through the cofferdam are a function not only of the initial, but also of the basic filtration resistance of the cofferdam.

If there are n rows of frozen ground cylinders, then

$$H_a = \sum_{i=1}^{i=n} (S_i \cdot F_{ai}). \tag{12}$$

By using the graph of the dependency $F_a = f(\varepsilon)$ plotted according to equation (7) (see Figure 4), it is easy to see that the largest value of H_a and consequently the largest anti-filtration effect with a given total number of freezing columns is obtained when the volumns are arranged in a single row and not when they are in multiple rows.

An analysis of formula (8) and an examination of the calculated graph shown in Figures 3 and 4 make it possible to draw the following basic conclusions.

1. As the frozen ground cylinders increase in size, the filtration rate steadily decreases. However, initially as long as the cylinders are small ($\varepsilon < 0.4-0.7$), the anti-filtration effect is insignificant.

2. The anti-filtration effect created by the frozen ground cylinders has a considerably greater effect on relatively thin cofferdams ($\chi < 4$) than on relatively thick ones ($\chi < 8$).

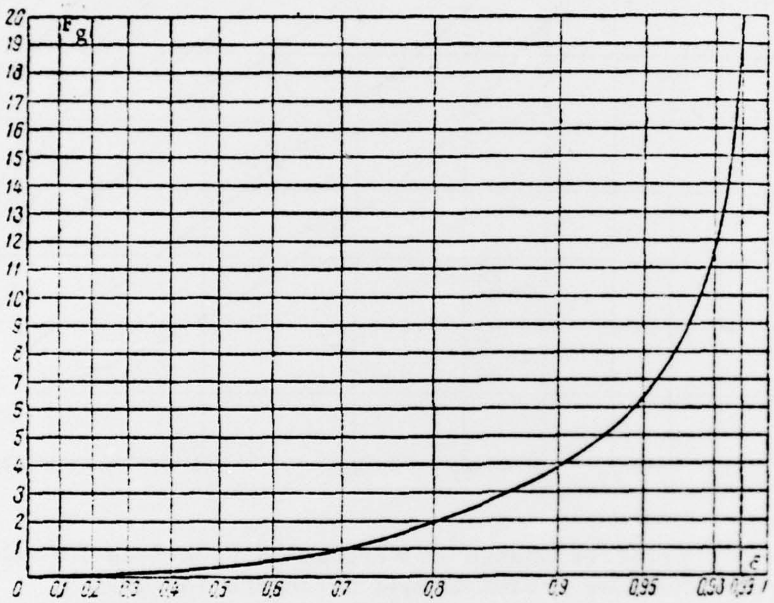

Figure 4. Additional Filtration Resistance As a Function of Relative Crowding in the Cofferdam Cross-Section.

3. It is necessary for the frozen ground cylinders to join completely since even small cracks ("windows") in a number of cases can greatly reduce the anti-filtration effect of the frozen ground screen.

4. From the viewpoint of the anti-filtration effect it is advisable for all of the frozen ground cylinders to be arranged in a single row.

In conclusion it should be noted that in preparing his manuscript for pressure, the author received very useful commentaries from S. N. Numerov.

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